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Note

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A pulsed reactor based on a proton linac is proposed as a safe pulsed neutron source for material sciences. An energetic proton beam is injected into a subcritical fissile-material target to multiply the number of neutrons initially produced by a spallation. In this assembly subcriticality is rather large to make sure the safety and to reduce a delayed neutron backgroud without a mechanically moving device. A 300 MeV proton linac which consists of an RFQ linac, an Alvarez linac and a disk-and-washer coupled cavity linac is proposed as an injector of this system. A radio-frequency system of 433 MHz for the proton linac which has been already developed at the ICR Kyoto University is suitable to get the neutron pulse duration of 50 μsec.

KEY WORDS: Pulsed neutron source/ Subcritical assembly/ RFQ/ DTL/ DAW

1. INTRODUCTION

The neutron beam has been a powerful tool for fundamental meterial sciences and their applications. A high flux nuclear reactor supplies a good continuous neutron beam but it becomes difficult recently to reach a consensus on construction of a nuclear reactor. An accelerator based spallation neutron source produces a good pulsed beam. But an accelerator for the high intensity spallation neutron source is very expensive. Some pulsed reactors with the mechanically moving device to change the reactivity with or without an electron beam injection have been developed[1]. The pulsed reactor is attractive because its average power is very low. But the mechanical device to change the reactivity is not so easy to make sure its safety.

On the other hand some accelerator driven power reactors have been proposed recently[2]. These are composed of proton accelerators and subcritical assemblies. The proton beam is much more effective to produce neutrons than the electron beam and the subcritical assembly becomes an energy multiplier. This system is very attractive for a transmutation of a high level radio-active waste and for a new kind of nuclear fuel cycle and eventually for a new safe energy production.

In this paper a pulsed reactor which consists of a proton linear accelerator and a subcritical assembly is proposed for a pulsed neutron source to be used in the field of scientific research at Kyoto University. The proposed facility should be safe, economical and complementary to the existing research reactor KUR, which would deliver continuous neutron beams.

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2. SUBCRITICAL ASSEMBLY

A high energy proton hits on a target to produce neutrons. Then the neutron is absorbed by fissile material which surrounds the target and another neutron is produced by the fission. This process is repeated and the total number of neutrons N_{tot} in the case of infinite material is expressed by

$$N_{tot}=N_1/(1-k) \tag{1}$$

where N_1 is the neutron number of the first step. The reproduction factor k is less than unity in the subcritical case. The enhanced factor $1/(1-k)$ becomes very large if k comes close to unity. A slightly subcritical reactor with a proton accelerator was proposed by Takahashi in which $k=0.99$ and the proton beam power could be small[2].

But the delayed neutron effect becomes also large in the case of small subcriticality. The delayed neutron becomes a between-pulse background for time-of-flight (TOF) experiments and increases the mean power of the reactor. Therefore, in the case of a pulsed reactor with the electron linac of which the subcriticality is usually very small, the reactivity should be changed in phase with the beam pulse of the injected electrons to reduce the background neutrons between pulses.

A high energy proton beam yields much more spallation neutrons comparing to the electron beam at the same beam power. The energy gain G of the subcritical assembly with energetic protons may be assumed about 20[2]. The subcriticality of the pulsed reactor based on a proton accelerator could be larger than the case of electron accelerator driven reactor. In the case of the large subcriticality the mechanical device to change the reactivity may not be necessary to reduce the background neutron. But the high energy and high intensity proton accelerator is expensive. Thus the optimum configuration should be searched under the condition of the necessary pulsed neutron beams.

On the other hand the rise time and the width of the neutron beam pulse are also affected by the subcriticality or the reactivity. The rise time and fall time of a pulsed power level of the subcritical reactor are order of μsec to 10 μsec and are not so short comparing to a spallation neutron source with a non-fissile target. Because of the limitation of the time resolution in the TOF experiment, a sharp and short pulse width order of submicro-second is necessary to make fast neutron experiments. But usual thermal or cold neutron experiments can be made by a long pulse of 50 μsec and a repetition rate of 50 Hz. Therefore the pulsed reactor is suitable for the thermal and cold neutron experiments.

On the contrary the ordinary electron linac is operated with a pulse width of about 1 μsec which is rather short to feed neutrons into the subcritical assembly to get a usual pulse length at the thermal neutron experiment. From this view point the proton linac which is usually operated with the pulse length of longer than 10 μsec is also preferable as an injector into the subcritical core comparing to the electron linac.

3. PROTON LINEAR ACCELERATOR

The higher energy proton beam produces the more spallation neutrons but the high energy accelerator is expensive. Thus at the first step we may have a plan to make a 300 MeV proton linear accelerator instead of a 1.5 GeV machine which is usually planed for the spallation neutron source. A main reason of this energy is that the neutron yield decreases abruptly at less than this energy. Above this energy the spallation neutron yield is proportional to the proton beam power. Then we can add a higher energy section with ease in the case of the linac.

The operation frequency of the linac should be high to achieve a compact and economical

Table 1. Characteristics of the ICR Kyoto University 7 MeV proton linac.

Ion source	multi-cusp field type, proton 50 keV
Accelerator structure	
RFQ (four vane type)	50 keV–2 MeV
Vane length	2,195 mm
Cavity diameter	170 mm
Charateristic radius	3 mm
Min. bore radius	2 mm
Intervane voltage	80 kV
Transmission efficiency	95% (30 mA)
DTL (Alvarez)	2 MeV–7 MeV
Cavity length	1,868 mm
Inner diameter	451 mm
Number of drift tubes	28
Focusing magnet	NdB iron permanent magnet
RF power source	
Klystron	Litton L-5773
Frequency	433.3 MHz
Peak power for each tube	1 MW
Repetition rate	180 Hz (Max)
Duty factor	1 % (Max)

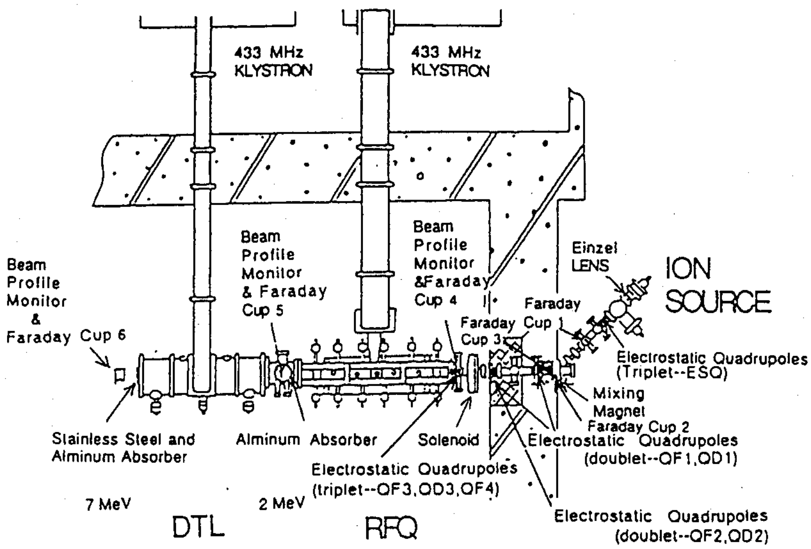

Fig. 1. Plan view of the 7 MeV proton linac at the ICR Kyoto University.

design. But a low frequency linac is easy to accelerate a high intensity beam. On the other hand a filling time of the RF power in an accelerator cavity becomes long at the low frequency. A compact 7 MeV proton linac with frequency of 433 MHz at Kyoto University which is composed of a radio frequency quadrupole (RFQ) linac cavity and a drift tube linac (DTL) cavity is now in operation[3]. The filling time in our DTL section is about 15 μsec and we have a beam pulse width of 50 μsec. Usual proton linacs are orerated at 200 MHz but it may be too low to make the pulse width of 50 μsec. Thus the 433 MHz linac must be suitable as the injector of the pulsed ractor for the neutron TOF experiment.

The characteristics of our 7 MeV linac is listed in Table 1 and the plan view is shown in Fig. 1. The DTL section of the proposed linac is to be extended to about 100 MeV. At around 100 MeV, the shunt impedance of the DTL cavity becomes lower than that of the 1,300 MHz disk-and-washer (DAW) cavity. Then a higher energy section of the proposed linac is to be a 1,300 MHz DAW structure to improve the shunt impedance, which has been previously studied[4]. We have proposed similar liancs for a multi-purpose 800 MeV accelerator system[5]. A cross section of the DAW cavity is shown in Fig. 2.

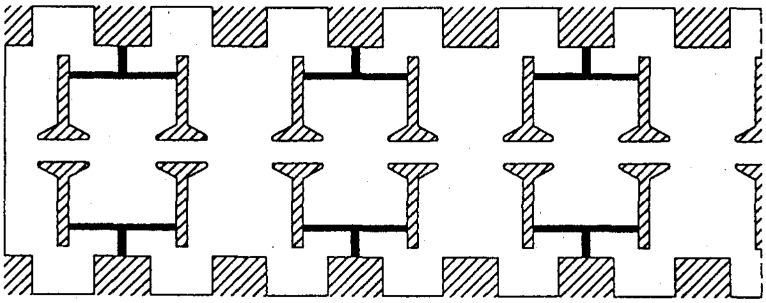

Fig. 2. Cross section of the DAW structure with biperiodic T support.

4. DISCUSSION AND SUMMARY

The pulsed neutron source which consists of a subcritical assembly and a proton linear accelerator is very desirable to be constructed at Kumatori site, where the 5 MW research reactor (KUR) is in operation. The desired peak power of the pulsed reactor may be more than 50 MW, which is determined by the subcriticality of the fuel assembly and the proton beam power. If the energy gain G is 20, a 180 MW reactor is obtained with a 300 MeV–30 mA proton beam. On the other hand we should avoid the between-pulse background from the delayed neutrons. More detailed design studies are necessary to fix the parameters. The reasonable proton accelerator for the first step design may be the proton linac which consists of a 433 MHz RFQ linac, a 433 MHz DTL and a 1,300 MHz DAW linac. The energy of the DTL is about 100 MeV and the energy of the final DAW linac is at least 300 MeV. We have already developed the 7 MeV proton linac which consists of the RFQ and the DTL and we are now constructing a DAW model cavity to study its performance in high power operation.

Detailed studies for the subcritical target assembly are not made yet. But we will soon begin to study in collaboration with researchers of the Kyoto University Research Reactor Institute (KURRI) because this pulsed neutron source will be proposed as a candidate of future

Table 2. An example of the proposed pulsed reator with a proton linac.

Accelerator	
Ion source	multi-cusp field type
RFQ section	2 MeV, 433 MHz
DTL section	100 MeV, 433 MHz
DAW section	300 MeV, 1,300 MHz
Beam intensity	30 mA at peak
Pulse width	50 μsec
Repetition	60 Hz
Neutron yield	10^{18} n/sec at peak
Subcritical assembly	
Fuel	^{235}U
Peak power	180 MW
Average power	600 kW
Neutrons	10^{19} n/sec at peak

projects of the KURRI at Kumatori site.

An example of the characteristics of the proposed system is listed in Table 2.

This system will be mainly used for the pulsed neutron experiments. But it is also a useful tool for a fundamental study of the incinerator of the nuclear waste and the Thorium-cycle power reactor by the proton beam accelerator.

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